Climate variability and the collapse of a Chinook salmon stock

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The collapse

After reaching a peak in 2002, returns of Chinook salmon to the Sacramento River declined rapidly to record lows in 2007 and 2008. The fishery was closed for the first time ever in 2008, and remained closed in 2009.

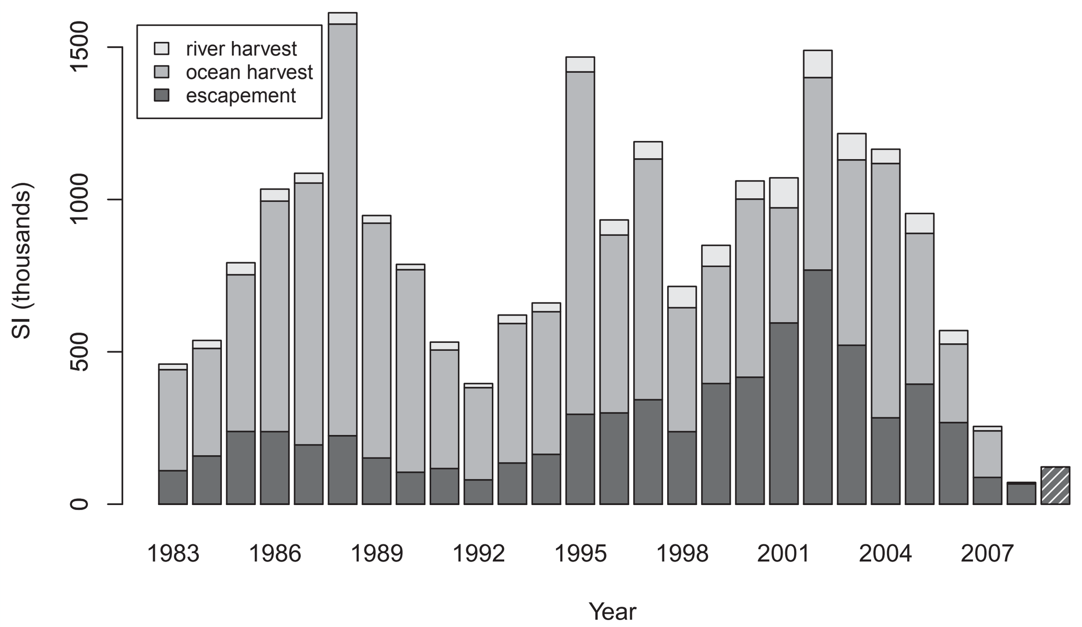
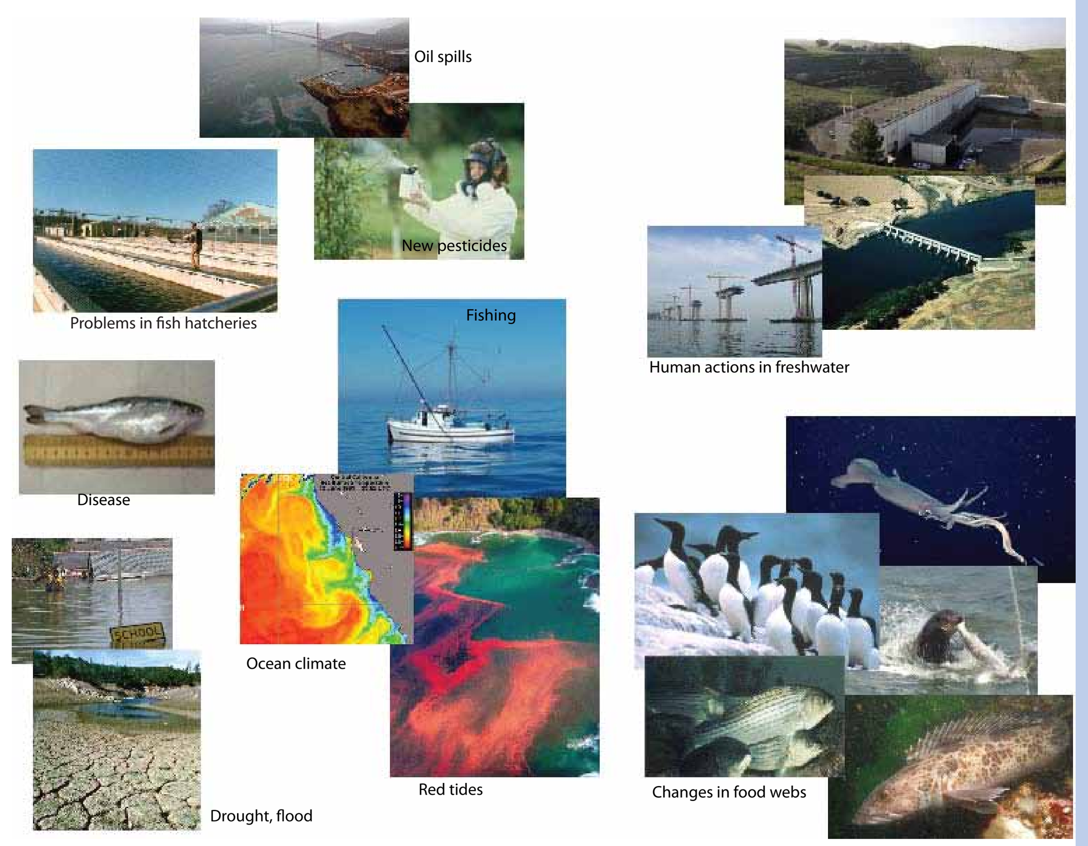


Fig. 1: The Sacramento River index off all-run Chinook abundance.

The suspects

The fisheries community proposed many potential causes for the collapse, including unusual climatic conditions affecting the river, estuary and ocean.



Conceptual approach

Salmon traverse a variety of ecosystems at particular times over their lifetime. When and where (in the life cycle of the cohort) did unusual mortality occur? When and where did unusual environmental conditions occur? The proximate cause of the collapse should lie at the intersection of these two lines of evidence.

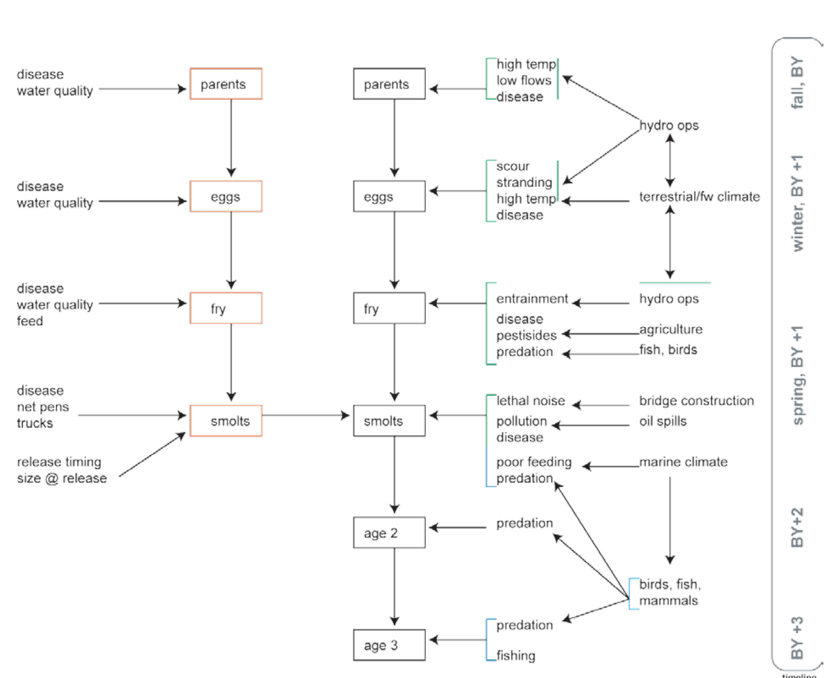


Fig. 2: A conceptual framework for interpreting the potential influence of environmental effects on a cohort of salmon. Many Chinook salmon are produced in hatcheries (orange pathway) where they are insulated from many freshwater environmental effects, but subject to others not experienced by fish in the wild. Most hatchery fish are released in the estuary, and hatchery and wild fish experience similar environments from that point on.

Clues

Patterns of survival and abundance for the 2004 and 2005 broods indicate that unusual mortality occurred in either the estuary or the ocean.

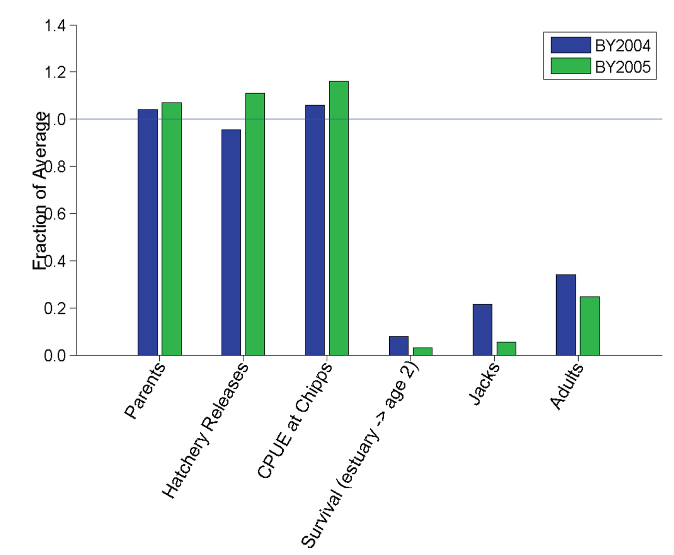


Fig. 3: Relative abundance or survival rate of the 2004 and 2005 broods.

Other salmon stocks in the region also suffered poor survival in the same period, suggesting a problem in a shared environment, e.g., the ocean.

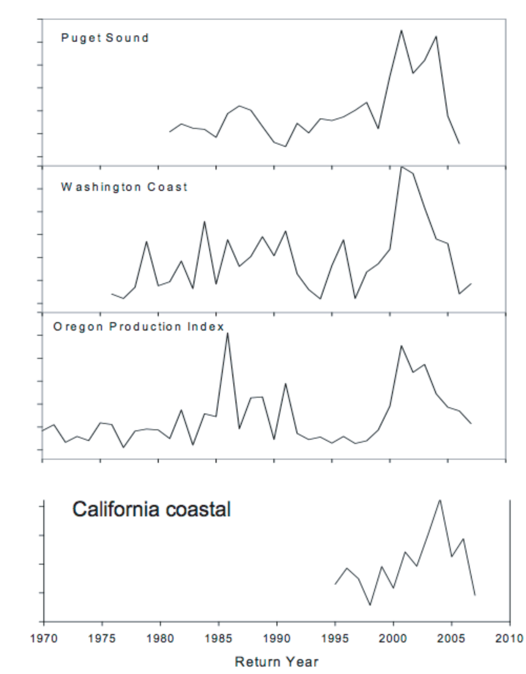


Fig. 4: Trends in abundance of coho salmon stocks in WA, OR and CA.

Freshwater and estuarine factors

Most freshwater, estuary and hatchery factors were either near normal, or were more favorable to salmon survival than normal. Exceptions were net-pen acclimatization of hatchery releases, which was not conducted for the 2005 brood, and the rate of diversion off reshwater from the Sacramento-San Joaquin delta, which reached record levels but only in the summer when the young salmon were already in the ocean.

Table 1: Summary off reshwater variables.

Variable	2005	2006
River flow	near normal	high
Water temp	OK	OK
No. of hatchery fish released	normal	normal
Size of hatchery fish	normal	normal
Disease outbreaks	no	no
Delta exports	high	near normal
Delta outflow	high	very high
Diversion rate	low	very low
DCC gates	mostly closed	entirely closed
Net pen acclimatization	43%	0%

Drought conditions, associated in the past with periods of poor salmon production, were not in effect.

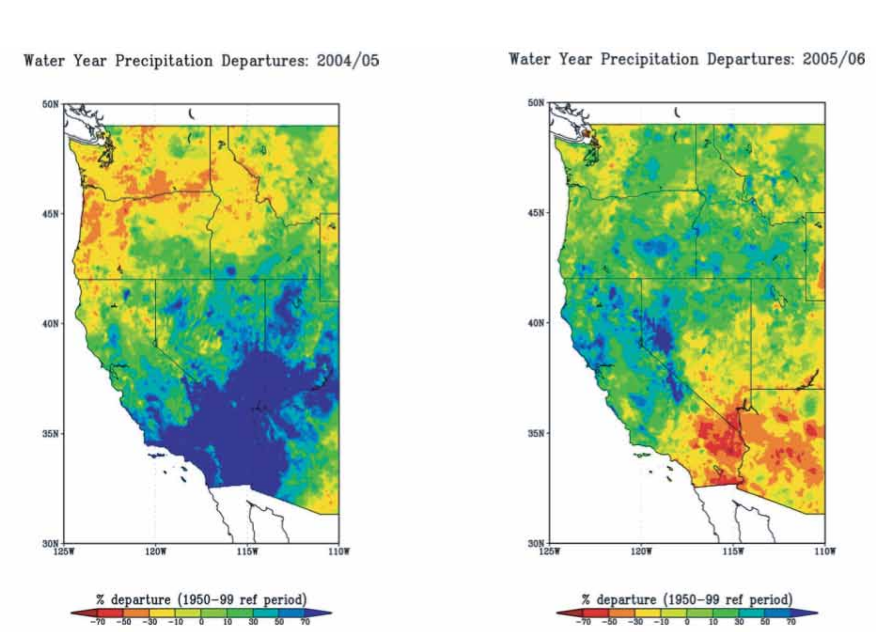


Fig. 5: Rainfall anomalies in 2005 and 2006.

Marine factors

Conditions in the California Current were quite unusual in the spring of 2005 and 2006, when juvenile salmon from the 2004 and 2005 broods entered the ocean. The spring transition was delayed, and sea-surface temperatures were warmer than normal.

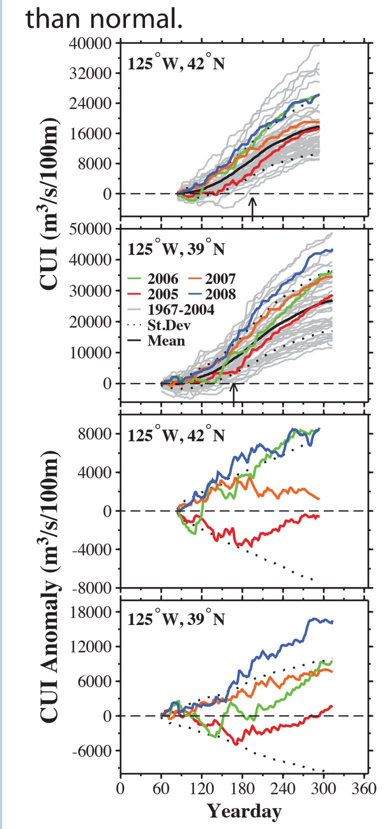


Fig. 6: Cumulative upwelling and anomalies

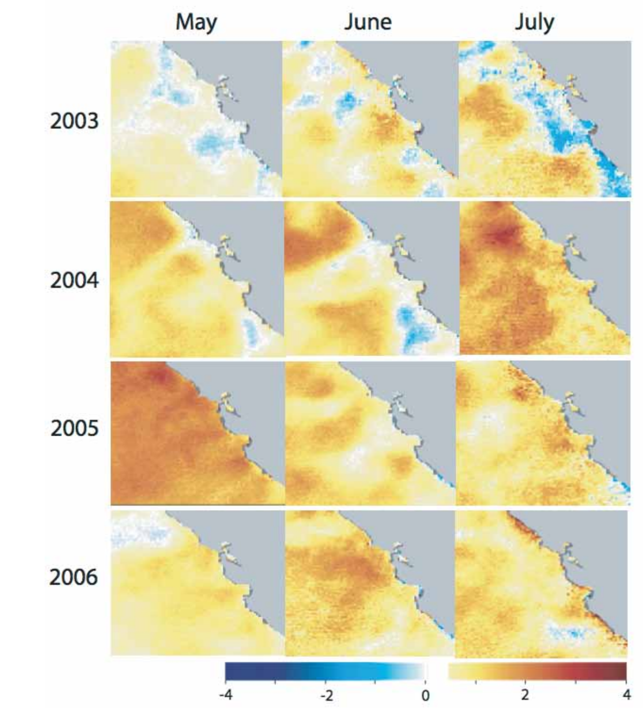


Fig. 7: Sea surface temperature anomalies

The ecosystem response

Biota in the California Current in 2005 exhibited highly unusual patterns of distribution, abundance, and reproductive success.

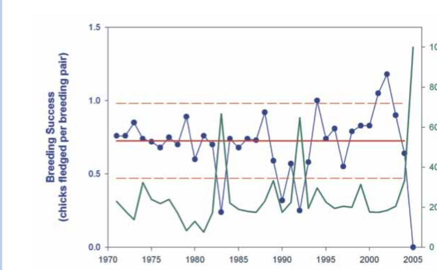


Fig. 8a: Seabird nest failure

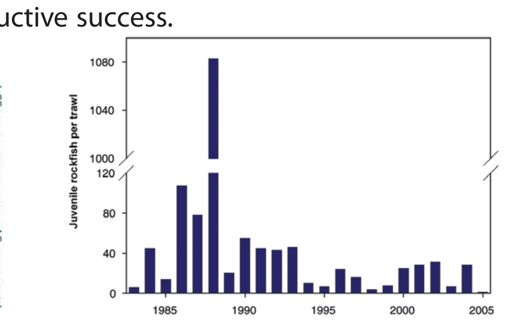


Fig. 8b: Sparse salmon prey

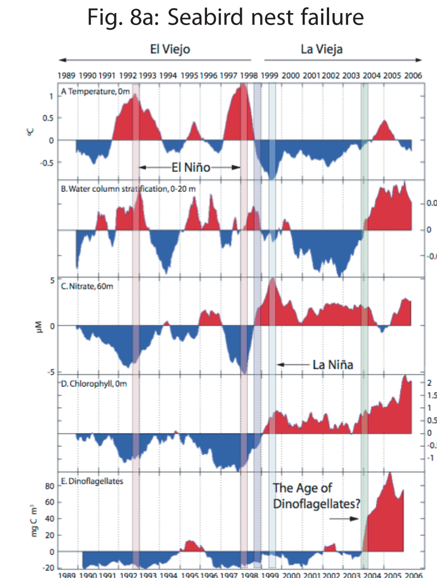


Fig. 8c: Shift to dinoflagellates

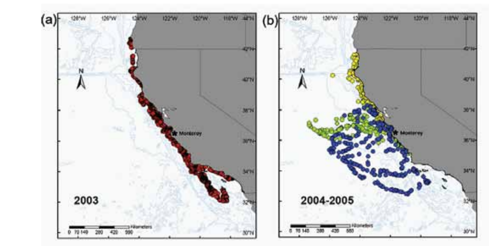


Fig. 8d: Sea lions foraging offshore

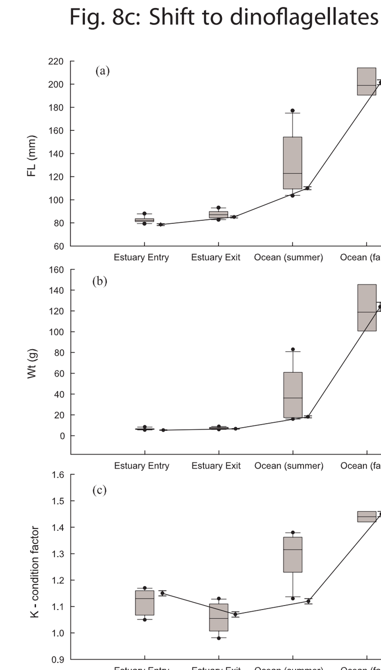


Fig. 8e: Starving juvenile salmon

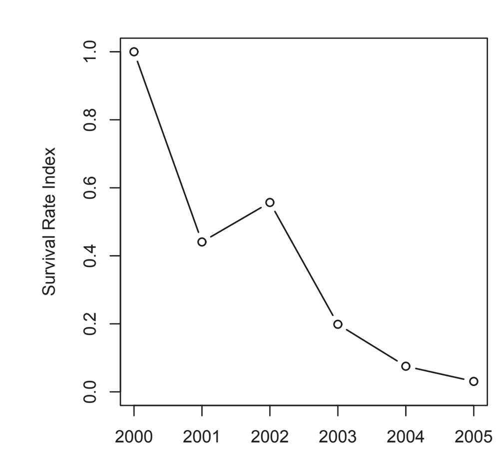


Fig. 8f: Poor salmon survival

References: 8a: Sydeman et al. 2006, Geo Res Let 33 L22S09; 8b: Brodeur et al. 2006, Geo Res Let 33 L22S08; 8c: MBARI Annual Report, 2006; 8d: Weise et al. 2006, Geo Res Let 33 L22S10; 8e: MacFarlane, in prep; 8d: unpublished.

Why it happened

The collapse of SRFC was unprecedented, and while ocean conditions were poor, physical observations were not outside the range of past observations. So, why the collapse? There are three possible explanations: it was just an unusual confluence of conditions; the ocean is changing; or the fish are changing.

Changing ocean?

Ocean climate and variability of salmon catch appear to be increasing. Is this a signal of global climate change?

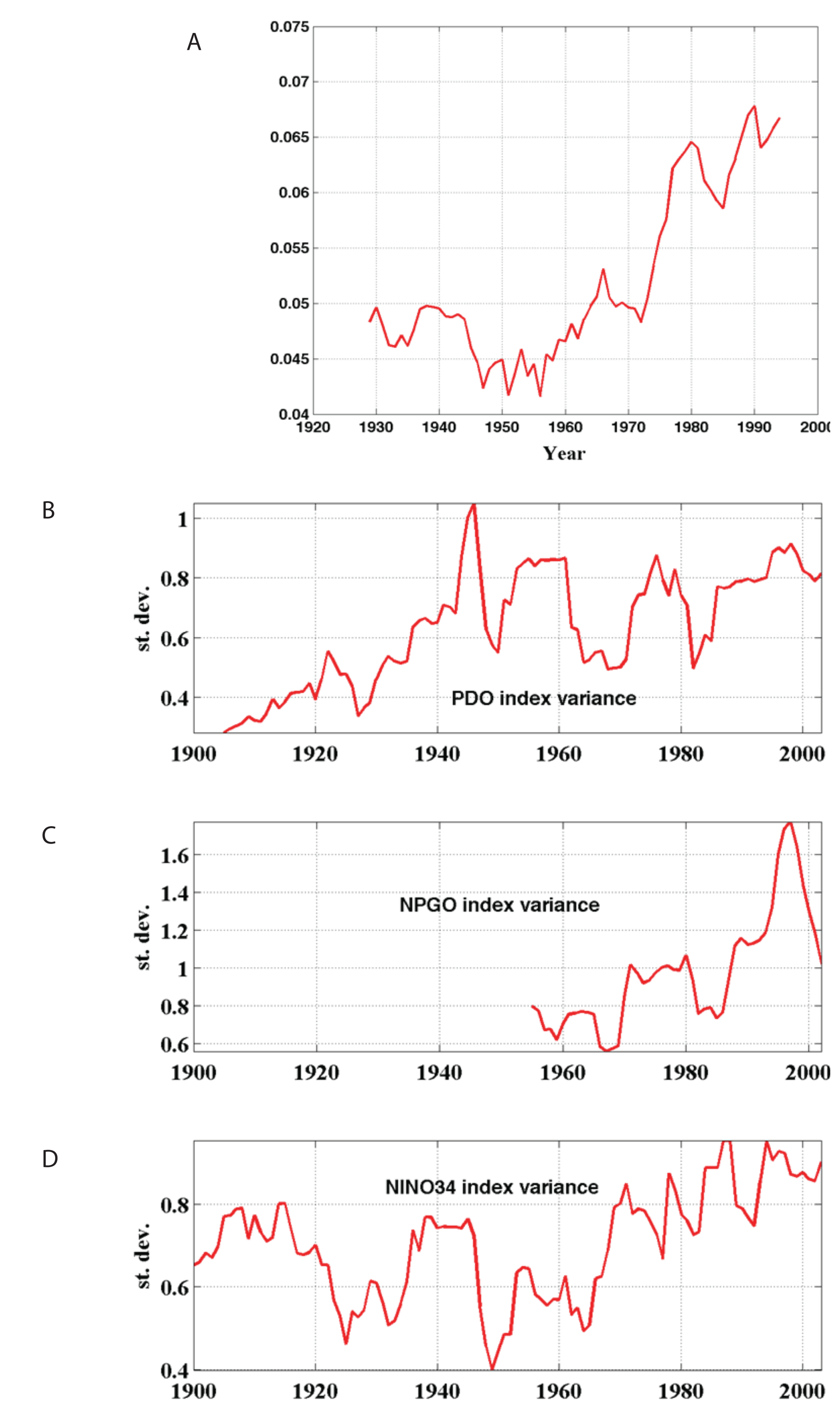


Fig. 9: A: Variability in landings of Pacific salmon. B) Variance in the Pacific Decadal Oscillation index. C) Variability in the North Pacific Gyre Oscillation index. D) Variability in the NINO34 index of the El Ni ño-Southern Oscillation.

For more information...

A detailed report is available on the web at http://swfsc.noaa.gov/publications/TM/SWFSC/NOAA-TM-NMFS-SWFSC-447.pdf

Changing salmon

The Sacramento River Chinook salmon stock was once comprised of a diverse assemblage of populations with significant life history diversity. Now it is mostly made up off all-run salmon produced in a few large hatcheries.

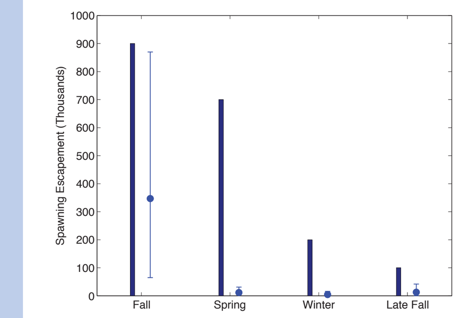


Fig. 10: Historic peak and current abundance of Chinook salmon races within the Central Valley.

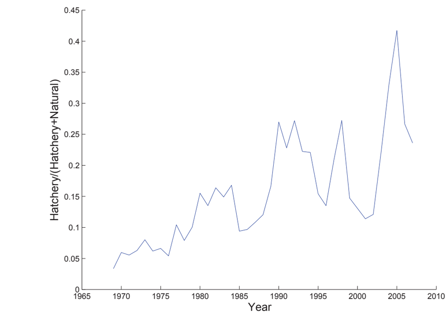


Fig. 11: Proportion off all-run Chinook returning to hatcheries.

The dynamics off all-run populations are highly correlated with each other, but not with remant populations from other runs.

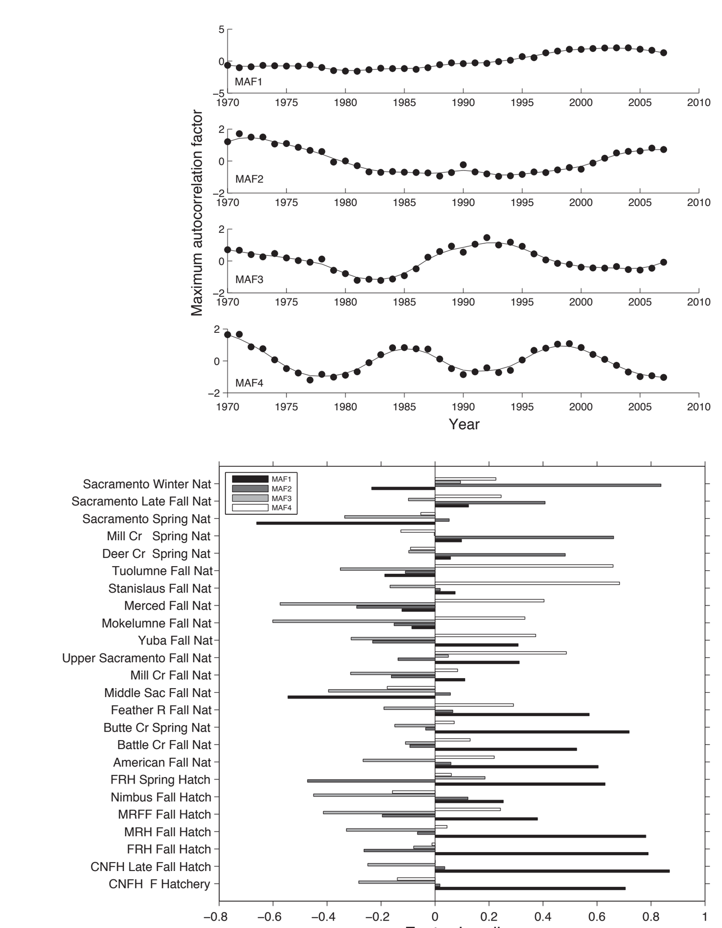


Fig. 12: Maximum autocorrelation factor analysis of Chinook salmon returns to the Sacramento River.

A conceptual model of the salmon decline

The loss of biocomplexity within Central Valley Chinook salmon, and its replacement by artificial production, has created a salmon stock that is increasingly vulnerable to climatic variation. When climate conditions improve, the stock will increase, but the next period of poor climate conditions will likely drive the stock to new record low levels. Reversing this process will require restoring the diversity and function of natural salmon habitats.